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(71) Applicant: BRUNSWICK CORPORATION, One Brunswick Plaza, Skokie Illinois 60077 (US)

(72) Inventor: Wrasidlo, Wolfgang J., 1219 Coast Boulevard, La Jolla California 92037 (US)
Inventor: Mysels, Karol J., 8327 Scenic Drive, La Jolla California 92037 (US)

(74) Representative: Allden, Thomas Stanley et al, A.A. THORNTON & CO. Northumberland House 303-306 High Holborn, London WC1V 7LE (GB)

(54) Improved membrane system and process therefor.

(57) There is disclosed, in one aspect, a membrane system useful for filtering a fluid, such as a liquid, which contains particles, such as bacteria, to be removed from the fluid. The membrane system comprises at least two members selected from the group consisting of at least one prefilter and at least one porous asymmetric membrane. The asymmetric membrane has a skin or shiny side and a support or dull side. The membranes are arranged parallel to and in initimate contact with one another such that the fluid passes through each membrane. In another aspect, there is disclosed a process for filtering such a fluid using the membrane system described above. This process comprises filtering such a fluid using this membrane arrangement so as to substantially eliminate passage of any particles through the membrane system.

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IMPROVED MEMBRANE SYSTEM AND PROCESS THEREFOR

BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates generally to membranes which are useful as ultrafilters and microporous membranes useful in separating materials. More particularly, this invention relates to a membrane system containing a prefilter and an improved integral asymmetric membrane having a skin and a porous support arranged so as to substantially eliminate the passage of undesired substances through the membrane system.

2. Description of the Prior Art and More Particular Background

Polymeric membranes are well known. These membranes may generally be classified according to their retentivity, i.e., the sizes of particles which they retain, or according to their effective pore size, as either ultrafilter membranes, which have the finest pores, or microporous (or microfilter) membranes which have coarser pores. The dividing line between ultrafilter membranes and microfilter membranes is between approximately 0.025 and 0.050 micrometers in pore size or smallest retained particle.

Membranes may also be classified according to the porosity difference or similarity of their two faces. Thus, membranes may be classified as symmetrical, when the two faces have similar porosity or as asymmetrical when the two faces differ in porosity.

An important characteristic of a membrane is its permeability to water which is measured by the volume of pure water which passes through a unit area of membrane per unit time. Water permeability is customarily expressed in units of cm/min-psi which represents the macroscopic velocity in cm/min at which water flows through the membrane when the driving pressure is one psi.

The flow of water through the membrane is, within wide limits, directly proportional to the applied pressure. In general, the permeability to water decreases as the retentivity of the membrane to solutes increases, because smaller pores offer more resistance to flow. This relationship, however, is not a simple one since the retentivity depends on the single smallest pore encountered by the liquid in

passing through the membrane, whereas the resistance to flow depends on the cumulative effect of all the pores through which this liquid must pass. Hence, membranes of similar solute retention having uniform pores throughout their entire thickness have lower permeabilities than those whose retentivity is due to a thin skin having the same pore size combined with a body or substrate of much larger pores. In other words, symmetrical membranes offer more resistance to fluid flow and therefore have slower flow rates compared to asymmetrical membranes of similar retentivity.

In addition to their retention characteristics, membranes may be characterized by their ability to resist plugging or their dirt-holding capacity. Plugging refers to a reduction of the filtration rate during the filtering operation as a function of the amount of liquid passing the membrane. In order to extend the lifetime of a membrane in a given filtration operation, it is customary to prefilter the fluid through a membrane or filter having higher flow rates and lesser retentivities, but still the ability to reduce severe fouling, or blocking, of the final membrane filter.

Structurally, membranes vary greatly and may generally be classified as either reticulated or granular. In the former, there is a three-dimensional open network of interconnecting fibrous strands and open interstitial flow channels. In the granular type structure, however, incompletely coalesced solid particles called granules leave an interconnected network of pores between them. Reticulated membrane structures generally have a higher porosity than granular membrane structures. (Porosity of membranes is

defined as (1- the relative density). Porosity is also defined as the ratio of the weight of a given volume of membrane to that of the bulk polymer forming the membrane.)

Polymeric membranes are generally made by preparing a solution of the polymer in a suitable solvent, forming the solution into a thin sheet, a hollow tube or hollow fiber, and then precipitating the polymer under controlled conditions. Precipitation may be carried out by solvent evaporation or by contacting the polymer solution with a nonsolvent.

U.S. Patent No. 3,615,024 discloses a method of forming porous polymeric membranes which are described as being highly asymmetric. The membranes produced according to that method are only slightly asymmetric, however, and have a permeability to water which is only slightly higher than that of symmetrical membranes of the same retentivity.

Membranes may also be classified as composite, supported or integral. Composite membranes comprise a very thin retentive layer attached to a preformed porous support. In a supported membrane, the actual membrane is attached to a strong sheet material of negligible retentivity. Integral type membranes are formed in one and the same operation having layers of the same composition. These layers may have very different properties, depending, in general, on whether the membrane is symmetrical or asymmetric.

Present membrane processing techniques are such that it is virtually impossible to ensure totally defect free membranes. Large defects or holes are, of course, visible to the naked eye and a membrane may be rejected on that basis alone. Smaller defects or holes of less than 100 microns

cannot be readily observed visually. Furthermore, particle passage through a membrane may take place if the pore size distribution of the membrane is large such that particles may pass through the largest size pores. The term "defect" as used in this specification and claims is meant to include not only true defects or holes which inadvertently occur in the membrane during processing and use, but also the largest pores of a membrane which naturally result from a large pore size distribution in the membrane. Furthermore, "defect" is a relative term in the sense that the definition depends upon the application for which the membrane is to be used. For example, in applications involving bacteria retention, a one micron hole would be considered a defect so that most microporous membranes would be considered defective. For other applications, holes as large as 100 microns would not be considered defects.

In certain applications, it is extremely important that no particle larger than that which the membrane is specified to retain pass through the membrane with the filtrate which is passing through. These applications include the use of sterilizing solutions where the presence of bacteria could have undesirable effects.

In other applications it is necessary to obtain a very pure filtrate while also ensuring that the particles which are being removed from the fluid are substantially completely recovered.

Since asymmetric membranes have not been available prior to the inventions disclosed in my copending patent applications (described below), the prior art, which employed

symmetric membranes, attempted to solve the problem caused by membrane defects by increasing the thickness of the membranes. This attempt has not proven completely satisfactory.

Improved asymmetric membranes and processes for their preparation are described in my copending patent applications Serial No. 291,927, filed August 11, 1981 and entitled "Improved Asymmetric Membranes And Process Therefor" and Serial No. 138,315, filed April 8, 1980 and entitled "Improved Asymmetric Membranes And Process Therefor." The disclosures of each of these two patent applications are hereby incorporated by reference.

While these membranes have certain extremely advantageous characteristics, and would generally be sufficient to retain all particles for which the membrane is designed, in certain cases there may be need for additional precautions to ensure that no particle passes through the membrane due to a defect or "hole" in the membrane, and, in other cases, there may be need to ensure a complete recovery of those particles.

The search has continued for membrane systems which possess these additional advantages. This invention was made as a result of that search.

OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, it is a general object of the present invention to avoid or substantially alleviate the above discussed problems of the prior art.

A more specific object of the present invention is to provide membrane systems which contain improved asymmetric membranes which may be used as ultrafilters or microfilters, have improved flow rates and dirt-holding capacities, and will not pass undesired particles through the membrane system even when each membrane of the membrane system contains a defect or hole.

Another object of the present invention is to provide a membrane system which enables one to recover the particles from the fluid.

Still another object of the present invention is to provide a process for filtering solutions using this membrane system.

Other objects and advantages of the present invention will become apparent from the following summary of the invention and description of its preferred embodiments.

In one aspect, the present invention provides a membrane system useful for filtering a fluid which contains particles to be removed from this fluid. The membrane system comprises at least two members selected from the group consisting of at least one prefilter and at least one porous asymmetric membrane which contains a skin side and an opposite side. The membranes are arranged parallel to and in intimate contact with one another such that the fluid passes through each membrane.

In another aspect, the present invention provides a process for filtering a fluid which contains particles to be removed from the fluid. This process comprises passing the fluid through the membrane system described above whereby

passage of particles through the membrane system is substantially eliminated.

The essence of the present invention is that, unlike the prior art method of attempting to reduce the probability of particle passage through defects by increasing membrane thickness, the present invention effectively solves the problem by statistically reducing the possibility of defect communication between the two membranes and/or filters. Whether the defects are true defects in the sense of a hole accidentally put into the membrane during production or use or simply the largest pores in a membrane having a large pore distribution, the present invention overcomes the problem of having particles pass through such a defect by statistically blocking the defects in a first membrane with the second membrane, and by statistically blocking the defects in the second membrane with the first membrane, as will be described in greater detail hereinbelow.

BRIEF DESCRIPTION OF THE DRAWING

Figure I illustrates a particularly preferred system of the present invention enclosed in a tube through which passes the fluid to be filtered.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention comprises, in one aspect, a membrane system useful for filtering a fluid which contains particles to be removed from the fluid. The "fluid" may be either a liquid or a gas and the "particle" may be any substance that one desires to remove from the fluid either

because the substance is a contaminant of the fluid or because the substance is valuable and it is economically desirable to recover it.

The membrane system comprises at least two members selected from the group consisting of at least one prefilter and at least one porous asymmetric membrane. The prefilter may be either a membrane, which could be either symmetric or asymmetric, or a non-membrane type prefilter, such as a polypropylene prefilter. Accordingly, the present invention contemplates the use of two or more asymmetric membranes, the combination of at least one asymmetric membrane with at least one symmetric membrane, and the combination of at least one asymmetric membrane with at least one non-membrane type prefilter such as a polypropylene prefilter.

The combination of two asymmetric membranes is particularly preferred for use in the present invention. This combination of two asymmetric membranes leads to four different configurations each possessing the advantage of extremely high retention even in the presence of defects in each membrane. The particular configuration chosen depends upon the application as will be set forth hereinbelow.

Each asymmetric membrane comprises a skin or shiny side and a dull or support side. By definition of asymmetry, the pores on the opposite faces of an asymmetric membrane differ in size. The skin or shiny side contains the smaller pores while the support or dull side, which is opposite the skin side, contains the larger pores. The size of the particle to be retained is such that it is larger than the largest pore in the skin absent a membrane defect.

These four configurations which are possible when the membrane system comprises two asymmetric membranes may be described in terms of a first and second membrane wherein the first membrane is defined as the one which is initially contacted by the fluid. The four configurations are: (1) the skin side of one membrane faces the skin side of the other; (2) the opposite side of one membrane faces the opposite side of the other; (3) the skin side of the first membrane faces the opposite side of the second; and (4) the opposite side of the first membrane faces the skin side of the second.

Each configuration has particular advantages depending upon the application. Configuration 1, for example, provides the advantage of substantially complete particle retention, particularly since the skin of the first membrane is in intimate contact with the skin of the second membrane so that lateral flow of fluid between the two skins is severely restricted. This configuration may advantageously be used in applications, for example, where it is necessary to substantially completely remove bacteria (using a microporous membrane) or viruses (using an ultrafiltration membrane) from a fluid. When safety or particle retention is the primary concern, configuration 1 should be selected. Configuration 1 is also advantageous because the skins of both membranes are protected and thus not exposed to the sometimes damaging effects of equipment and handling during the processing of the membrane system.

Configuration 3 also provides the advantage of very complete particle removal from the fluid. This configuration is chosen, however, for applications where higher throughput is of greater concern. Configurations 2 and 4 are

selected when one wishes to recover the particles and still obtain a very pure filtrate. Configuration 4 is selected over configuration 2 when the purity of the filtrate is of primary concern since it has been found that particle retention is greater when the skin side is upstream.

When the membrane system comprises two porous asymmetric membranes, it is not necessary that one membrane have the same size pores in its skin as the other membrane. Indeed, for many applications, it is preferred that the first membrane have substantially larger pores than the second membrane so that the first membrane acts as a prefilter for the second membrane thereby increasing the efficiency of the membrane system by inhibiting plugging.

The asymmetry of the porous membranes used in the present invention may be measured by the ratio of the average pore diameter of its two faces. The asymmetry factor (defined as the ratio of the average pore diameter of the pores of the dull side to the average pore diameter of the pores of the shiny side) for the membranes used in this invention is from about 10 to 20,000. For microporous membranes. the asymmetry factor is generally from about 10 to about 300, typically from about 50 to about 150, and preferably from about 75 to about 125. While the invention is particularly advantageous when two microporous membranes are used, for example, to remove bacteria from a liquid, it also includes the use of two ultrafiltration membranes for use, for example, in removing viruses from a fluid.

The polymers which may be used to produce the membranes useful in the present invention include broadly any

polymer generally used to produce membranes and particularly those set forth in my copending patent applications Serial Nos. 291,927, and 138,315, discussed hereinabove. Polymers which have been found to be particularly valuable in preparing membranes useful in the instant invention include polysulfones, polyamides, polyimides, polyarylamides, polyvinylidene halides including polyvinylidene fluoride, polycarbonates, polyacrylonitriles including polyalkylacrylonitriles, polystyrene, and polyarylhydrazides. Mixtures of two or more polymers may also be used to make these membranes.

Preferred polymers within the above-noted groups for use in making these membranes include Lexan polycarbonate, Union Carbide P-3500 polyarylsulfone, Nomex polyamide, polyhexamethylene terepthalamide, and polyvinylidene fluoride.

A particularly preferred polymer for use in making these membranes is Union Carbide P-3500 polyarylsulfone. When this particular polymer is employed, it has been found that an average molecular weight of 30,000 is needed in order to obtain a coherent membrane with a reticulated structure. The upper limit of molecular weight is approximately one million. The use of polyarylsulfone with molecular weights in excess of one million is undesirable because of the formation of polymer gels due to chain entanglement. The molecular weight range of the other polymers that may be useful in the present invention differs, of course, depending upon the particular polymer employed.

The membrane system of configuration 1, which is particularly preferred, is illustrated in Figure I. Figure I shows fluid 14 passing in tube 11 through membranes 12 and 13 which have shiny or skin sides 16 and 18 and support or

dull sides 15 and 17. For the purpose of understanding the invention, the two membranes 12 and 13 are illustrated in such a way that the skins of each are not in intimate contact. The present invention requires that the two skins be in intimate contact, however.

Fluid 14 passes from right to left in the drawing passing first through membrane 13 and then through membrane 12. Support side 15 of membrane 13 acts as a built-in prefilter, greatly increasing the dirt-holding capacity of the membrane system. The fluid encounters the largest pores first and later encounters pores having gradually decreasing size with the smallest pores--those in skin 16--being encountered last. Hence larger particles are retained at various levels leaving many more pores available for flow than if they were all retained on one plane at the skin. If the membrane were not highly asymmetric, this advantage would not exist since approximately the same amount of retained matter fouls both sides of the membrane because the pore sizes on both sides are approximately the same.

When this membrane 13 is placed with its skin side 16 next to the skin side 18 of membrane 12, there results an additional safety precaution against the passage through the membrane system of an undesired particle. When membranes are used with large membrane areas, such as in cartridge filters, the ability to detect bubbles passing through individual large pores becomes less as the flow these pores produce becomes swamped by diffusive flow. Thus, the bubble point integrity test (described below) becomes meaningless.

The use of the second membrane reduces the probability of a defect in the first membrane communicating with a defect in the second. In the unlikely event that a defect occurs in each of the membranes, the chances of having two such defects within 50 microns of each other when the two membranes are arranged in accordance with the present invention is about one in a million. Even if such relatively close proximity should occur, the chances of a particle being able to pass from the first defect to the second are minimal. Between defects, there exists a tremendous number of intervening pores in the second membrane which intercept the flow of liquid coming from the first defect and therefore also stop any particles carried by it. Furthermore, the intimate contact of the two smooth surfaces restricts any lateral flow of fluid which, in turn, decreases the chance of two defects cooperating to provide the passage of undesirable particles.

The present invention also provides a process for filtering a fluid which contains particles to be removed from that fluid. That process comprises passing the fluid through the membrane system described above.

The present invention is further illustrated by the following example. All parts and percentages in the example as well as in the specification and claims are by weight unless otherwise specified.

EXAMPLE

This example illustrates the preparation of the membrane system of configuration 1.

A mixture of 73.4 parts by weight dimethylformamide and 15.6 parts by weight tertiary amyl alcohol is formed. To this mixture is slowly added 11 parts of granulated Union Carbide P-3500 polyarylsulfone which has been previously air dried and stored in a vacuum until used. After addition of the polysulfone, the mixture is vigorously stirred for a minimum of eight hours in the absence of moisture.

This mixture is then placed in a dispensing tank at 112 degrees F by agitating in a partial vacuum sufficiently to eliminate air bubbles but not so great as to cause non-solvent loss. The turbidity is then adjusted by adding either solvent or nonsolvent as required to obtain an optical density of 0.70 $\pm$ 0.03 at 420 nanometers with a 2 centimeter light path to form a casting dope.

This casting dope is transferred into a casting trough (which is heated to a temperature of 112 degrees F) through a ten micron rated filter. The dope is cast onto a siliconized paper and quenched in a water bath which is pre-heated to 100 degrees F.

The membrane is rinsed in deionized water which contains a surfactant. It is then dried at 250 degrees F. It has a mean pore diameter of 0.1 micrometers, a bubble point in water, using nitrogen gas, of 55 psi, and a water permeability of 3 cm/min-psi.

This membrane is then formed into two 90 mm diameter discs. These discs are randomly perforated with a needle to give ten to twenty micron holes. About fifty holes are made in each disc. The various membrane systems set forth in Table I below are tested for "bubble point."

The so-called "bubble point" test is an integrity test for a membrane. It is used to determine the largest pore size in the membrane. The bubble point test involves passing a gas, such as air, through a wetted membrane and determining the pore size as a function of the pressure needed to push a bubble through that pore of the membrane. The bubble points of various membrane systems using the membrane prepared in this example are set forth in Table I below:

Table I

Membrane System	Bubble Point (psi)
Single layer before perforation	55
Single layer after perforation	0
Double layer: skin to skin	70
Double layer: skin to dull	3-5
Double layer: dull to dull	3-5

As may be seen therefrom, the double layer, skin to skin, membrane system has a substantially higher bubble point, and thus substantially greater integrity, than either of the other double membrane combinations or the single membrane which is perforated. The double layer, skin to skin, membrane system with perforated membranes even has a higher bubble point than the single layer, unperforated, membrane system.

The double layer, skin to skin, membrane system retains bacteria <u>pseudonomas diminutia</u> completely at a challenge of 10^{10} per cm^2 of membrane surface.

Three of the membrane systems of Table I are placed

into cartridges and tested for reduction of bacteria *pseudonomas diminutia* as set forth in Table II:

Table II

Membrane System	Bacteria Reduction Ratio
Single layer before perforation	$10^5 - 10^7$
Double layer: skin to skin	10^{10}
Double layer: skin to dull	$10^5 - 10^8$

In the double layer, skin to skin, membrane system, complete retention of the bacteria *pseudonomas diminutia* is observed even when the second membrane has a bubble point of only 35 psi but complete retention is not observed when the bubble point of the second membrane is only 25 psi.

The membrane systems of the present invention may be placed within filtration systems which include spiral wound and pleated cartridges, single and multiple disc systems, and tubular configurations.

The principles, preferred embodiments, and modes of operation of the present invention have been described in the foregoing specification. The invention which is intended to be protected herein, however, is not to be construed as limited to the particular forms disclosed, since these are to be regarded as illustrative rather than restrictive. Variations and changes may be made by those skilled in this art without departing from the spirit of the invention.

CLAIMS:

1. A membrane system useful for filtering a fluid which contains particles to be removed from said fluid, said membrane system comprising at least two members selected from the group consisting of at least one prefilter and at least one porous asymmetric membrane which contains a skin side and an opposite side, said membranes and prefilters being arranged parallel to and in intimate contact with one another such that said fluid passes through each membrane and prefilter.

2. The membrane system of claim 1 wherein said system comprises a first asymmetric membrane and a second asymmetric membrane wherein said first asymmetric membrane is initially contacted by said fluid.

3. The membrane system of claim 2 wherein said opposite side of said first asymmetric membrane is initially contacted by said fluid.

4. The membrane system of claim 2 wherein said skin side of said first asymmetric membrane is initially contacted by said fluid.

5. The membrane system of claims 3 and 4 wherein the size of the pores in the skin of one of the membranes differs substantially from the size of the pores in the skin of the other membrane.

6. The membrane system of claim 3 wherein said skin side of said first membrane faces said opposite side of said second membrane.

7. The membrane system of claim 4 wherein said opposite side of said first membrane faces said opposite side of said second membrane.

8. A membrane system useful for filtering a fluid which contains particles to be removed from said fluid, said membrane system comprising two porous asymmetric membranes which each contain a skin side and an opposite side wherein said membranes are arranged such that the skin side of one membrane is in intimate contact with the skin side of the other membrane whereby said arrangement substantially eliminates passage of said particles through said membrane system even in the presence of a defect in each of said membranes.

9. The membrane system of claim 8 wherein each of said two membranes has substantially the same pore size in each of the skins.

10. The membrane system of claim 8 wherein each of said two membranes is a microporous membrane.

11. The membrane system of claim 8 wherein each of said two membranes is made of polysulfone.

12. The membrane system of claim 8 wherein each of said two membranes is placed within a filtration system.

13. A process for filtering a fluid which contains particles to be removed from said fluid comprising passing said fluid through a membrane system comprising at least two members selected from the group consisting of at least one prefilter and at least one porous asymmetric membrane which

contains a skin side and an opposite side, said membranes and prefilters being arranged parallel to and in intimate contact with one another such that said fluid passes through each membrane.

14. The process of claim 13 wherein said system comprises a first asymmetric membrane and a second asymmetric membrane wherein said first asymmetric membrane is initially contacted by said fluid.

15. The process of claim 14 wherein said opposite side of said first asymmetric membrane is initially contacted by said fluid.

16. The process of claim 14 wherein said skin side of said first asymmetric membrane is initially contacted by said fluid.

17. The process of claims 15 and 16 wherein the size of the pores in the skin of one of the membranes differs substantially from the size of the pores in the skin of the other membrane.

18. The process of claim 15 wherein said skin side of said first membrane faces said opposite side of said second membrane.

19. The process of claim 16 wherein said opposite side of said first membrane faces said opposite side of said second membrane.

20. A process of filtering a fluid which contains particles to be removed from said fluid comprising passing said fluid through a membrane system comprising two porous asymmetric membranes which each contain a skin side and an opposite side wherein said membranes are arranged such that the skin side of one membrane is in intimate contact with the skin side of the other membrane, such that said arrangement substantially eliminates passage of said particles through said membrane system even in the presence of a defect in each of said membranes.

21. The process of claim 20 wherein each of said two membranes has substantially the same pore size in each of said skins.

22. The process of claim 20 wherein each of said two membranes is a microporous membrane.

23. The process of claim 20 wherein each of said two membranes is made of polysulfone.

24. The process of claim 20 wherein each of said two membranes is placed within a filtration system.

25. The process of claim 20 wherein each of said two membranes is made of a wholly aromatic polyamide.

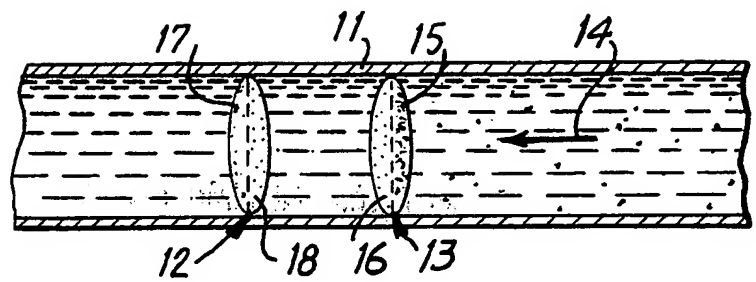

FIG. I

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(71) Applicant: BRUNSWICK CORPORATION
One Brunswick Plaza
Skokie Illinois 60077(US)

(72) Inventor: Wrasidlo, Wolfgang J.
1219 Coast Boulevard
La Jolla California 92037(US)

(72) Inventor: Mysels, Karol J.
8327 Scenic Drive
La Jolla California 92037(US)

(74) Representative: Allden, Thomas Stanley et al,
A.A. THORNTON & CO. Northumberland House 303-306
High Holborn
London WC1V 7LE(GB)

(54) **Improved membrane system and process therefor.**

(57) There is disclosed, in one aspect, a membrane system useful for filtering a fluid, such as a liquid, which contains particles, such as bacteria, to be removed from the fluid. The membrane system comprises at least two members (12, 13) selected from the group consisting of at least one prefilter (13) and at least one porous asymmetric membrane (12). The asymmetric membrane (12) has a skin or shiny side and a support or dull side. The membranes are arranged parallel to and in intimate contact with one another such that the fluid passes through each membrane. In another aspect, there is disclosed a process for filtering such a fluid using the membrane system described above. This process comprises filtering such a fluid using this membrane arrangement so as to substantially eliminate passage of any particles through the membrane system.

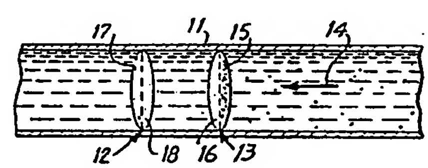

FIG. I

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European Patent Office

EUROPEAN SEARCH REPORT

0083489
Application number

EP 82 30 6759

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
A	US-A-3 707 231 (W.E. BRADLEY) * Positions 15,26 * ---	1	B 01 D 13/00 B 01 D 13/04
A	DE-A-2 622 461 (DIDIER) * Positions 1,7 * ---	1	
A	DE-A-2 704 099 (BAXTER TRAVENOL) * Figure 2 * ---	1	
A	DE-A-2 518 614 (KANEGAFUCHI) * Claim 1 * -----	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl. 3)
			B 01 D 13/00 B 01 D 13/04 A 23 C 9/142 C 02 F 1/44 C 07 G 7/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	30-08-1985	KUEHN P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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